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The nature of semantic priming by subliminal spatial words. Embodied or disembodied?

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Abstract

Theories of Embodied Semantics (ES) suggest that a critical part of understanding what a word means consists of simulating the sensorimotor experience related to the word's referent. Some proponents of ES have suggested that sensorimotor activations are mandatory and highly automatic during semantic processing. Evidence supporting this claim comes from masked priming studies showing that unconsciously perceived spatial words (e.g. up, down) can directly modulate action performance on the basis of their meaning. However, a closer look reveals that such priming effects can be explained also in terms of symbolic (disembodied) semantic priming or nonsemantic mechanisms.

In this study we sought to understand whether sensorimotor processing takes place during language understanding outside awareness. We used spatial words as a test-bed and across six experiments we teased apart the possibility that action priming could be explained by: (i) nonsemantic mechanisms; (ii) symbolic semantic priming; or (iii) embodied semantic priming. The critical finding is that when symbolic and nonsemantic mechanisms were prevented, allowing only for a genuinely embodied semantic priming, no effect was found. Conversely, facilitation emerged in the same experimental paradigm when embodied priming was prevented and symbolic priming was allowed. Despite extensive testing, we found no evidence that unconsciously perceived words can activate sensorimotor processes, although these words are processed up to the semantic level. We thus conclude that sensorimotor activations might need conscious access to emerge during language understanding.

Keywords: Embodied Semantics, Masked Priming, Consciousness, Space, Unconscious processing.

According to theories of Embodied Semantics (ES; Barsalou, 1999; Gallese & Lakoff, 2005; Kiefer & Pulvermüller, 2012; Pulvermüller, Shtyrov, & Ilmoniemi, 2005; Barsalou, 2008) word meaning is based, at least in part, on sensorimotor representations. Understanding a word requires the activation of sensorial (e.g. visual, auditory, tactile) and motor representations that are usually associated with the perceptual and/or motor experience of the word's referent (Glenberg & Gallese, 2012). For instance, understanding the word "grasp" will require the activation of the perceptual and motor system that is usually active when someone performs (or sees someone else performing) the action of grasping. A general assumption of ES is that thinking, acting and perceiving are based on (partly) shared neural structures.

ES is usually contrasted with more traditional "disembodied" theories of semantics, which hold that word meaning is symbolically represented by activating concepts stored in a modality-independent fashion (Landauer & Dumais, 1997; Mahon & Caramazza, 2008). Although disembodied theories differ from each other (see Meteyard, Cuadrado, Bahrami, & Vigliocco, 2012 for a review), they share the hypothesis that perception and action on the one hand and word's semantics on the other are subserved by different neurocognitive structures. Accordingly, the sensorimotor system is not needed to understand the meaning of words. At most, the involvement of sensorimotor activations during language comprehension is considered the product of post-semantic processing via indirect routes, such as the activation of working memory processes that may involve sensorimotor areas (Meteyard et al. 2012).

The fact that sensorimotor information can activate during language understanding is well established, both in the behavioral and in the neuroimaging literature. For instance, several behavioral experiments have shown that semantic processing can modulate action execution and perception (Boulanger, Roy, Paulignan, Deprez, Jannerod, & Nazir, 2006; Glemberg, Sato, & Cattaneo, 2008; Glemberg & Kaschak, 2002). Indeed, simply reading a word can activate sensorimotor brain areas specifically related to the meaning of that word (e.g. the premotor cortex for “grasp”, auditory areas for “doorbell”; Willems, Hagoort, & Casasanto, 2010; Kiefer, Trumpp, Herrnberger, Sim, Hoening, & Pulvermuller, 2012). Advocates of a strong version of ES suggest that the involvement of the sensorimotor system in semantic processing is highly automatic (Boulanger et al., 2006; Pülvermuller, Hauk, Nikulin, & Ilmoniemi, 2005) and necessary (Ansorge, Kiefer, Khalid, Grassl, & König, 2010). To date, the best evidence for this claim comes from masked priming experiments suggesting that sensorimotor representations are activated even when words are processed outside of consciousness (Ansorge et al. 2010; Boulanger, Silber, Roy, Paulignan, Jannerod, & Nazir, 2008; Dudshig, de la Vega, De Filippis & Kaup, 2014).

It is well established that words can be processed up to the semantic level even when unconsciously perceived, at least in some cases (deWitt & Kinoshita, 2014; Dehaene & Naccache, 2001; Quinn & Kinoshita, 2008; see Kouider & Dehaene, 2007 for a review). One of the most fruitful paradigms used in psycholinguistics to investigate unconscious processing in language understanding is masked priming (Evett & Humphreys, 1981; Forster & Davis, 1984). In a typical masked priming experiment, a prime is presented briefly, sandwiched between a forward mask and a backward mask (e.g. AFNBGTYHDR) before the appearance of a target. In the majority of the cases, participants are not aware of the presence of the prime, and this lack of awareness precludes the possibility that they could intentionally elaborate the word meaning (Forster & Davis, 1984; Forster, 1998). Nevertheless, the prime word does influence participants’ responses, at least in some circumstances. For instance, people are typically faster in classifying the target if prime and target are from the same semantic category (e.g. *Mars* and *Venus*, which are both tokens of the category *PLANETS*), compared to when prime and target are unrelated (e.g. *Mars* and *Crocodile*; Quinn & Kinoshita, 2008). Unconscious semantic priming has been obtained with a number of different types of stimuli and experimental designs, but all these effects were traced back to one of four different mechanisms.

The classic account in the psycholinguistic literature attributes semantic priming to some intrinsic relationship between the semantic representations of the prime and the target words. Semantically related words are considered as closely interconnected nodes in a semantic network (e.g., Meyer & Schvaneveldt, 1971), so that that seeing the prime makes it easier to process a related target due to spreading activation from one node to nearby nodes (e.g., Bueno & Franck–Mestre, 2002; Lupker, 1984; McRea & Boisvert, 1998). In the Spreading Activation account sensorimotor information is not considered a fundamental part of semantic representations.

A different type of symbolic account of semantic masked priming was recently proposed by deWitt and Kinoshita (2014a, 2014b), and is based on Evidence Accumulation and Source Confusion. This proposal holds that word recognition is a process of evidence accumulation for a hypothesis dictated by the task (Norris & Kinoshita, 2008). For instance, in a semantic classification task, participants are engaged in collecting relevant information (evidence) in order to make a semantic decision (e.g., accept or reject the hypothesis that the target word refers to an animal). The close temporal proximity of prime and target leads to source confusion, and the evidence accumulated via the prime is used to validate the hypothesis over the target. According to this mechanism, it is the decision required by the task that drives the priming effect (deWitt & Kinoshita, 2014b). This may hold in paradigms where primes and targets have some form of semantic relationship, e.g., belong to the same, task–relevant category. For example, when people are asked to decide whether the target word is a planet, seeing Venus as a prime provides evidence for a YES response, thus making easier to address the target word Mars (Quinn & Kinoshita, 2008). Critically, however, primes and targets do not necessarily have to be related in order for priming to emerge. For example, in a task where people have to make an upward movement when they see a blue spot and downward movement when they see a red one, seeing spatial words as primes (e.g., *up*, *sky*, vs. *down*, *ground*) would provide evidence for either an upward or a downward response (e.g., Dudschig, de la Vega, De Filippis, & Kaup, 2014). Thus, a priming effect can be observed also when prime and target are unrelated. This is different from the Spreading Activation account, where priming is entirely attributed to primes-target relationships, independently of task requirements (deWitt & Kinoshita, 2014b). Like in the Spreading Activation account, there is no particular role for motor or perceptual representations in the Evidence Accumulation account.

According to the Stimulus-Response Mapping mechanisms, the prime can induce facilitation by directly activating the response action required by the target (e.g., pressing a left or right key), by virtue of some short–term, ad–hoc association created by the task. This mechanism is likely to take place when the same words are used both as targets and primes (Damian, 2001), and a small set of stimuli is repeated many times in the course of the experiment. Under these conditions, target words become quickly associated with their corresponding response action. For instance, in an experiment where participants have to classify words as pleasant or unpleasant, the target word *love* would become associated with the button for the *pleasant* response and the target word *death* would become associated with the button for the *unpleasant* response. If these same targets are then shown as primes, they may boost their corresponding responses by virtue of these associations, thus making congruent trials (e.g., *love–FLOWER*) quicker than incongruent trials (e.g., *death–FLOWER*). Contrary to the two previous mechanisms, this mechanism does not necessarily require that the prime is processed up the semantic level (Abrams & Greenwald, 2000; Damian, 2001; Kouider & Dehaene, 2007). The non-semantic nature of this mechanism has been clearly demonstrated by Abrams & Greenwald (2000). In their experiment, after the target words *smut* and *bile* were repeatedly classified as unpleasant during the task, the subliminally presented word *smile* (which is composed of fragments of the words *smut* and *bile*) facilitated unpleasant responses, instead of pleasant ones. On the opposite side, *tumor* facilitated pleasant responses after that the words *tulip* and *humor* were repeatedly presented as target. It was the learned association between (fragments of) the target words and the response action, instead of the semantic value of the primes that was driving the priming effect.

The fourth mechanism is Embodied Priming (Ansorge et al. 2010; Boulanger et al. 2008; Dudschig et al. 2014). Similar to the Stimulus-Response Mapping mechanisms, the unconscious prime can facilitate or inhibit the response action required by the task. Yet, the effect is due to the long-term meaning of the prime word and not to the short-term association between that word and a particular response during the task. For instance, when a prime word like *up* is processed unconsciously, congruent sensorimotor representations are automatically activated (e.g., motor programs for upward movements) so that a congruent response movement, such as pressing an upward located key, will be facilitated compared to an incongruent one. In this case the priming effect can take place independently of the semantics of the target word as long as the response action required by the task is semantically related to the prime. Such a priming mechanism would provide support for strong theories of embodied semantics because it would indicate that meaning activates motor programs outside awareness and very early during word identification

Embodied Priming has been claimed in a number of studies (Ansorge et al. 2010; Boulanger et al. 2008; Dudschig et al. 2014), whose results, however, seem to be open to alternative interpretations upon a closer look. Ansorge and colleagues (2010), for instance, tested embodied semantics using a masked priming paradigm with directional words referring to the vertical axis (e.g. *up*, *above*, *down*, *below*). In their Experiment 1 participants had to classify target words as referring to upper or lower spatial positions by pressing keys that were physically located in the upper and lower part of space, respectively. Although the same set of spatial words appeared both as primes and targets, the prime and target were never the same word in a given trial. Participants were faster in congruent trials (e.g., *up* and *above*) compared to incongruent ones (e.g., *up* and *below*). The authors attributed the priming effect to embodied mechanisms according to which spatial primes automatically activated response actions (moving upward/downward) on the basis of their meaning: When the motor program activated by prime and target was congruent (e.g. up-above) responses were faster compared to incongruent trials (up-below). Yet, priming effect in this case can also be explained in terms of nonsemantic stimulus-response mapping (since the same words are used as prime and targets) or symbolic mechanisms (unconscious primes facilitate the processing of related target words). A disembodied account was indeed supported in their Experiment 2, where they assigned participants a non-canonical response code: Subjects had to press the upper key for words such as *below* or *down*, and the lower key for words such *above* and *up*. Results showed that upward primes (e.g., *up*) facilitated responses to upward targets (e.g., *above*), and therefore downward movements. Similarly, downward primes facilitated downward targets even though they were associated with upward movements. This pattern of results clearly favors disembodied mechanisms, since the priming effect is independent from the action response associated with words. Notably, the priming effect with a canonical mapping was smaller than the priming effect with a non–canonical mapping. Ansorge and colleagues took this difference to mean that at least part of the facilitation seen with canonical mappings was due to Embodied Priming. According to them, neither symbolic mechanisms nor stimulus–response mappings would predict any difference between canonical and non–canonical mappings. However, this is questionable. From a Stimulus-Response Mapping perspective, participants facing a non–canonical mapping may have had to suppress the activation of the canonical mapping in order to follow the instructions and perform the experiment correctly; and this may well have caused weaker priming. This hypothesis is supported by the overall higher RTs in Experiment 2 (with non canonical mapping) compared to Experiment 1 (with canonical mapping; ~840 ms vs. ~736 ms). Clearly, there is no embodiment in this account of Ansorge et al.'s results.

Using a mouse-tracking paradigm, Tower-Richardi and colleagues (Tower-Richardi, Brunyé, Gagnon, Mahoney& Taylor, 2012) asked participants to move a computer mouse toward a left, right, up or down location on the screen following a target directional word (e.g. *up*) or an arrow. Movement trajectories were influenced by masked spatial primes denoting absolute spatial coordinates (i.e. east, north, west, south). Although this experiment shows nicely that absolute and relative spatial coordinates are associated to each other in our mind, the priming effect it is not necessarily due to unconsciously activated motor programs. Evidence Accumulation and Source Confusion can also explain the effect, with the spatial primes providing evidence for making the task dictated decision of moving up, down, left or right. Moreover no objective measure of prime visibility (e.g. d-prime) is provided in this paper.

Another paper that seems to support embodiment outside of awareness is Trumpp, Traub and Kiefer (2013). In an ERP experiment, participants were asked to silently read action–related words (e.g., *typewriter*) or sound–related words (e.g., *banjo*), which were preceded by the masked presentation of primes that could be either in the same semantic category (*typewriter* preceded by *hammer, banjo* preceded by *thunder*) or not (*typewriter* preceded by *streetlight*, *banjo* preceded by *cradle*). The authors report priming effects between 100 and 180ms after target presentation, showing a reduction of target-related activity with different topography and partially different neural source depending on the target category (sound, action). Although the authors concluded that sensorimotor features were thus activated unconsciously, it is also possible that the modulatory effect took place at the symbolic semantic level when words were unconsciously perceived and then cascaded down to modulate sensorimotor activation due to the conscious processing of the target (Mahon & Caramazza, 2008). Although these results may support sensorimotor activity due to conscious language processing, they cannot be taken as evidence for unconscious embodied semantics.

Although other masked priming studies have been interpreted in favor of ES (Boulenger et al. 2008; Dudschig et al.2014), the results tell a partially different story. For instance, in the study by Dudschig and colleagues (Dudschig et al. 2014) participants had to categorize visible colored rectangles by moving toward and pressing either an upper or a lower key. Targets were preceded by masked words referring to objects with a canonical spatial position (e.g. *hat* or *foot*). Any priming here could not be attributed to short–term association between primes and responses because primes were never seen as targets. A purely symbolic account based on simple spreading activation is also untenable, because hats and feet are not semantically related with specific colors. Priming may be expected, however, according to the embodied interpretation of Ansorge et al.'s (2010) findings—words like *hat* and *nest* should make upward movements faster, and words like *feet* and *ground* should prime downward movements. (Interestingly, this is what emerges in studies where the priming word is overtly presented to the participants, e.g., Lachmair, Dudschig, De Filippis, de la Vega, & Kaup, 2011). However, the opposite was found: Upward movements were slower after up-related primes, and downward movements were slower after down-related primes. Although the authors interpret these data in embodied terms anyway, it is clear that it is very difficult to reconcile these results with the evidence provided by Ansorge et al. (2010).

A similar instance of inhibitory priming was reported previously in a study by Boulanger and colleagues (Boulanger, Silber, Roy, Paulignan, Jeannerod, & Nazir, 2008).

Unconsciously perceived action words produced a diminished lateralized action potential and slower wrist acceleration during a grasping task, compared to nouns not associated with action. The authors suggested that the interference was due to competition for common cortical resources between semantic processing and action preparation and execution (see also Boulanger et al. 2006). Nevertheless, Boulanger and colleagues found that sequences of consonants (designed to be the control condition) interfered with action execution as well as action verbs, suggesting that negative priming might be due to non-semantic aspects of the primes.

To sum up, there are experiments in the literature claiming support to strong theories of ES based on masked semantic priming that are interpreted in embodied terms: Unconsciously perceived words automatically activate sensorimotor processes related to their long-term meaning. However, upon closer examination, these findings can also be explained by non-embodied accounts, and provide data that are at least partially inconsistent. This paper aims to address these issues, thus clarifying the nature of semantic masked priming triggered by spatial words.

In six experiments we progressively excluded the possibility that action modulation by subliminal words could be explained by (i) short-term stimulus-response associations, (ii) symbolic relationships between prime and targets or (iii) the Evidence Accumulation mechanism. To preview our results, we found a positive priming effect only when at least one of these non-embodied priming mechanisms could take place. Conversely, we showed that when the possibility of symbolic priming is prevented, allowing only for a genuinely embodied effect, neither facilitation nor inhibition is observed. Importantly, in the same experimental paradigm, when embodied priming is prevented and symbolic priming is allowed a priming effect emerges again.

Experiment 1

This experiment is a close replication of Ansorge et al. (2010) Experiment 1. Participants saw spatial words and had to classify them according to a canonical response mapping: They had to press the higher key if the word referred to the higher part of space (e.g., above) or press the lower response key if the word referred to the lower part of space (e.g., below), on a vertically oriented response pad. Target words were always preceded by a masked prime that was also a spatial word, either congruent (above–up) or incongruent (below–up). Each word appeared as both a target and a prime, but not in the same trial. Under these conditions, priming may be due to (i) symbolic priming based on Spreading Activation, (ii) symbolic priming based on Evidence Accumulation and Source Confusion, (iii) stimulus-response mapping, (iv) embodied priming, (v) or a combination of all these mechanisms. This experiment serves three purposes: (a) setting a baseline from which we can progressively rule out the four candidate mechanisms above; (b) ensure that masked semantic priming based on spatial words can be obtained in Italian, and (c) ensure that our experimental settings at Milano Bicocca do not justify possible differences between our results and those of Ansorge et al. (2010).

Methods

Participants. Twenty-four university students at Milano Bicocca (18F, mean age=25 years) were recruited for this study. They all reported normal or corrected-to-normal vision, no neurological or reading problems, and were native Italian speakers. Participants were paid 8 euros or given course credits in exchange for their time.

Stimuli. Prime and target stimuli were 8 Italian spatial words referring to position (or change in position) on the vertical axis: su (up), giù (down), sopra (above), sotto (below), salita (ascent), discesa (descent), alto (high), and basso (low). Upward and downward words were matched for number of syllables and frequency of occurrence (4.98 ± .91 vs. 4.77 ± .84; data are taken from SUTBLEX–IT, Crepaldi, Amenta, Mandera, Keuleers, & Brysbaert, 2015, and are expressed in Zipf units, Van Heuven, Mandera, Keuleers, & Brysbaert, 2014). Each of the eight words was presented as a target, preceded by one of the other seven words as a prime—there was no pair where the prime and the target were identical. Half of the pairs were semantically congruent, i.e., primes and targets referred to the same part of space (e.g., *su–alto*, up–high), whereas half were incongruent, i.e., primes and targets referred to different parts of space (e.g., *giù–alto*, down–high).

Apparatus and procedure. Participants performed first a word categorization task on the target words (the experimental task proper), and then, immediately after, a prime visibility task.

In the categorization task, participants were asked to judge whether spatial words referred to the upper/lower part of space, and to press one of two vertically–arranged buttons accordingly, i.e., the upper button for upward words, and the lower button for downward words. Instructions always referred to the keys in terms of their color (green or red; counterbalanced across subjects) and never in terms of spatial coordinates (e.g. upper/lower key). Participants were told that a fixation point would appear first, followed by a random string of uppercase letters to announce the appearance of the target word, which would be shown lowercase. No mention was made about the presence of a prime word.

The trial timeline is illustrated in Figure 1. A fixation cross was displayed for 750 ms, followed by a forward mask, which consisted of 10 random uppercase letters and stayed on the screen for 200ms. This first mask was immediately followed by the prime word, shown in lowercase letters for 33ms (four screen refreshes at 120 Hz). The prime was followed by a backward mask (33ms), identical to the previous one, and finally by the target word, which remained on the screen until the participants produced a response. Participants received negative feedback (the screen turned red) if their answer was wrong or if their RT exceeded 1250 ms.

The experiment consisted of 480 trials. Before starting with the experiment, each participant received a practice block of 32 trials. Trials were uniquely randomized for each participant, and were divided into six blocks, between which participants took a one–minute break. This part of the experiment lasted approximately 25 minutes overall.

After participants had finished the experimental task, they were asked whether they noticed a word being presented just before the target appeared. Participants were then informed about the presence of a prime, and the prime visibility task started. This consisted of 160 trials, whose timeline was identical to that of the experimental trials. However, participants were now asked to focus on the prime word. In order to make sure they knew where the prime was within the trials, before starting the task participants were shown two examples where the prime duration was tripled (100ms), so that the prime became fully visible. Participants engaged in one of the three prime identification tasks, assessing prime identification at three different levels of processing (Ansorge et al., 2010). Eight participants just did the experimental task on the primes, i.e., were asked to classify the prime words by pressing the upper key for upward primes and the lower key for downward primes. Another eight participants were asked to decide whether primes and targets were spatially congruent, i.e., they referred to the same part of space. A final third of the participants were asked to decide whether the prime was a real word vs. a string of identical uppercase letters (e.g., GGGGGGG). Instructions always referred to the keys in terms of their color (green or red) and never in terms of spatial coordinates (e.g. upper/lower key). This was true for all three versions of the prime-visibility test.

No feedback on either response times or error rates was provided and participants could take all the time they needed to give a response. Each participant performed a practice block of 16 trials before engaging in the prime visibility task. On average, the prime visibility block lasted approximately eight minutes.

Participants were tested individually, seated at a distance of approximately 57 cm from the monitor in a dimly lit room, and used headphones to block any outside noise. The head was supported by a chin-rest in order to ensure a constant viewing distance and a forward-leaning posture. All stimuli were presented at the center on a 27–inch ACER monitor with a refresh rate of 120 Hz, and were displayed in light gray on a black background. The display of the stimuli and the collection of the responses were controlled by Matlab (Mathworks, Naticks, MA), using Psychtoolbox functions (Brainard, 1997; Pelli, 1997).

Response times were collected through a custom–made response box placed in front of the subject. The response box was equipped with three buttons, arranged vertically. Participants were asked to press the central button in order to initiate the trials, and to keep it pressed until they were ready to offer a response, i.e., move towards either the upper or the lower button. The upper and lower buttons were equally distant from the central one, and were marked with colors (red and green). In order to exclude any color influence, the orientation of the colored buttons was counterbalanced between participants such that the green button was on the bottom for half of the participants and on the top for the other half of participants.

-- Figure 1 about here --

Results

Target-response task. Inaccurate trials (less than 1%) were excluded from the RTs analysis.

Trials for which the RT was above 1250ms, so that the subject received an error feedback (3%) were also considered as errors and excluded from the analysis. In order to reduce the effect of extremely long and short RTs, those individual datapoints standing at more than 2 standard deviations from each participant's mean (~5% of the correct trials) were also removed from the analyses (like Ansorge et al. 2010). The overall mean response time was 704 ms.

A 2–by–2 ANOVA on the log-transformed RTs revealed a significant main effect of Congruity, $F(1, 23)= 42.49$, $p< 0.001$, $\eta^2 = 0.649$. The responses in the congruent condition were faster (mean RT= 695ms) than in the incongruent condition (mean RT= 714ms). The factor Congruity interacted with Movement Direction, $F(1, 23)= 5.04$, $p= 0.04$, $\eta^2 = 0.18$, indicating that the congruity effect was slightly greater for downward compared to upward movements. Critically, however, the congruity effect was significant with both downward and upward movements (Downward: 22ms, $F(1, 23)= 35.54$, $p< 0.001$, $\eta^2 = 0.61$; Upward: 16ms, $F(1, 23)= 32.04$, $p< 0.001$, $\eta^2= 0.58$). The main effect of Movement Direction did not reach significance, $F(1, 23)= 0.56$, $p= 0.46$, $\eta^2 = 0.024$. No effect emerged in the error rate analyses.

Prime visibility task. No participants reported having noticed the prime during the experimental task. From the performance in the prime visibility task we computed individual d-prime values as an index of prime perceptibility (Stanislaw & Todorov, 1999). Hits and False Alarms were defined accordingly to the task requirements, that is, differently for each of the three prime visibility tasks. The average d-prime value was very low overall (mean= 0.04, SD= 0.27), and it was not significantly different from zero ($t(23)= 0.68$, $p= 0.5$). The average d-prime values were comparable across prime visibility tests (semantic judgment= -0.03; congruity judgment= 0.12; letter judgment= 0.01; $F(2,21)= 0.12$, $p= 0.89$). Overall, d-prime values and priming effects were not correlated ($r = 0.13$; $t(22)= 0.63$, $p= 0.53$).

Discussion

Our results fully replicated those of Ansorge et al.'s (2010) experiment 1—upward primes facilitated responses to upward targets with upward movements, and downward primes facilitated responses to downward targets with downward movements. This: (i) shows that Italian spatial words can yield masked priming effects as their German counterparts do; (ii) shows that Ansorge et al.'s effect can be replicated with our specific experimental settings, so that an eventual lack of priming in following experiments could not be attributed to this factor; and (iii) sets the baseline for further exploration into what mechanism generates the effect.

We started by tackling the Stimulus-Response Mapping account, which was made viable, in our first Experiment, by the fact that prime words were also used as targets. In Experiment 2, we used non–overlapping sets of prime and target words so that we excluded any possibility of a task–induced, stimulus–response mapping. If a congruity effect is found, then at least part of the priming effect observed in Experiment 1 was due to semantic mechanisms. If, instead, the semantic congruity effect fades away, then the mechanism that produced the priming effect in the first experiment is likely to be non–semantic in nature (Damian, 2001).

Experiment 2

Methods

Participants. Twenty-four new participants (five males and 19 females, mean age: 23 years) took part in Experiment 2. Participants were paid with 8 Euros or given course credits in exchange for their time.

Stimuli. Prime and target stimuli were the same Italian spatial words used in Experiment 1. However, they were now divided into two distinguished lists, so that su (up), giù (down), sopra (above), sotto (below) were only used as primes, and salita (ascent), discesa (descent), alto (high), and basso (low) were only used as targets.

Apparatus and Procedure were exactly the same as in Experiment 1.

Results

Target-response task. Two participants were excluded from the analyses, one because of a failure with the experimental apparatus and one because s/he didn't comply with the experimental requirements (s/he always pressed the *yes* key during the prime visibility task). After the exclusion of these participants, data were pre–processed exactly as in Experiment 1, which resulted in the exclusion of ~9% of trials. The overall mean response time was 681ms.

A 2–by–2 ANOVA on logarithmically-transformed RTs revealed no main effect of Congruity, $F(1, 21)= 1.22$, $p= 0.28$, $\eta^2 = 0.05$, no effect of Movement Direction, $F(1, 21)= 2.02$, $p= 0.17$, $\eta^2 = 0.09$, and no interaction between the two, $F(1, 21)= 2.97$, $p= 0.1$, $\eta^2 = 0.12$. The average response times in the congruent condition and in the incongruent condition were 680ms and 682ms, respectively. No effect emerged in the error rate analyses.

A Mixed ANOVA with Congruity as a within-subjects factor and Experiment (Exp.1, Exp.2) as a between-subjects factor substantiated the observation that the priming effect was stronger in Experiment 1 compared to Experiment 2 ($F(1, 44)= 23.90$, $p< 0.001$, $\eta^2 = 0.35$).

Prime visibility task. No participant reported having noticed the prime, just as in Experiment

1. The average d-prime value was very low (0.03, SD=0.21), and not significantly different from zero (t(21)= 0.66, p= 0.52). Average d-prime values were comparable across prime visibility tests (Semantic judgment= 0.07; Congruity judgment= -0.1; Letter judgment= 0.13; F(2,19)= 1.30, p= 0.3). D-prime values and priming effects were not correlated (r= 0.27; t(20)= 1.29, p= 0.21).

Discussion

The results of Experiment 2 show that no priming effect emerges with spatial words when non-semantic stimulus-response mapping is prevented by using different sets of primes and targets (see Damian 2001; Abrams & Greenwald, 2000; for similar results). This supports the hypothesis that the priming effect observed in our Experiment 1 was almost entirely due to stimulus-response associations, and was therefore not semantic in nature.

Although these results may cast doubts about the presence of a genuine semantic priming (embodied or disembodied) in Experiment 1 (and, arguably, in the Ansorge et al. Experiments), it does not rule out the possibility that unconscious semantic priming can take place under different conditions. The absence of semantic priming could be due to the fact that the duration of the prime display was too short to allow the appropriate semantic processing for the majority of the subjects, resulting in a weak and instable effect (Draine & Greenwald, 1998; Grainger, Diependaele, Spinelli, Ferrand, & Farioli, 2003; Greenwald, Draine & Abrams, 1996). In Experiment 3 we increased the duration of the prime display from 33ms to 50ms, so as to see whether a slightly longer presentation time allows for symbolic and/or embodied priming to emerge, while remaining outside awareness. A prime duration of ~50 ms has been used in several masked priming experiments (e.g. Quinn & Kinoshita, 2008; deWit & Kinoshita, 2014b; Grainger, Diependaele, Spinelli, Ferrand, & Farioli, 2003) and allows for robust semantic priming by keeping the prime invisible for the large majority of participants. Like in Experiment 2, separate sets of primes and targets were used, so as to exclude any contribution from stimulus–response mapping.

Experiment 3

Methods

Participants. A new set of 24 students at the University of Milano Bicocca were recruited in this experiment. Sixteen were females, and their mean age was 23 years. All participants reported no neurological problems, normal or corrected–to–normal vision, and were native Italian speakers.

Stimuli, Apparatus and Procedure were identical to those used in Experiment 2, with the only exception that primes were shown for 50ms, followed by a 50ms backward mask.

Results

Target-response task. The overall accuracy rate was ~99%. Data were prepared for the analysis as in Experiment 1 and 2, which excluded ~8% of trials. The overall mean response time was 685ms. A 2–by–2 ANOVA over RTs logarithms revealed a main effect of Congruity (F (1,23) = 33.03, $p < 0.001$, $\eta^2 = 0.59$, Figure 2). In the congruent condition participants were faster (mean RT= 677ms) than in the incongruent condition (mean RT= 693ms). There was also a main effect of Movement Direction, F (1,23)= 5.44, $p = 0.03$, $\eta^2 =$ 0.19, indicating faster response movements in the upward direction irrespective of the prime. The Congruity by Movement Direction interaction was not significant, F (1,23)= 0.43, $p =$ 0.52, $\eta^2 = 0.02$.

An ANOVA on the arc-sine transformed error rates revealed a main effect of Congruity, $F(1, 23) = 6.57$, $p = 0.02$, $\eta^2 = 0.22$, indicating that participants were more accurate in congruent trials compared to incongruent ones (99.4% vs. 99.0%). There was no effect of

Movement Direction, $F(1, 23)= 0.03$, $p= 0.85$, $\eta^2 = 0.001$, and no interaction between the predictors, $F(1, 23)= 0.08$, $p= 0.78$, $\eta^2 = 0.003$.

A Mixed ANOVA with Congruity as a within–subjects factor and Experiment (Exp. 2, Exp. 3) as a between–subjects factor proved that the priming effect was stronger in Experiment 3 compared to Experiment 2 ($F(1, 44)= 17.81$, $p< 0.001$, $\eta^2 = 0.29$).

Prime visibility task. One participant reported noticing the presence of a prime during the target–response task, at least on a few trials; the other 23 reported being completely unaware of it. Overall, the average d-prime value was 0.43 (SD= 0.80). Although significantly different from zero, $t(23)= 2.62$, $p= 0.01$, this value is widely taken to indicate that the prime was effectively masked from perceivers' awareness (e.g., Kouider & Dupoux, 2005). Average d-prime values were comparable across prime visibility tests (Semantic judgment= 0.48; Congruity judgment= 0.23; Letter judgment = 0.58; $F(2,21) = 0.75$, $p= 0.48$). Priming effect and d-prime values correlated significantly ($r=.50$; $t(22)= 2.71$, $p= 0.01$).

In order to rule out the possibility that prime visibility was the main driver of the priming effect, we also analyzed the data using the Greenwald regression method (Greenwald, Klinger, & Schuh, 1995). As illustrated in Figure 2, we regressed priming against d–prime, both averaged by participants. Facilitation is considered to happen outside awareness when the 95% Confidence Interval (CI) of the regression line at the origin lies entirely above the x axis, i.e., priming is estimated to be significantly higher than zero when d–prime is 0. This is exactly what we found in the data of Experiment 3.

-- Figure 2 about here --

Discussion

A significant priming effect emerged in Experiment 3, with congruent prime-target pairs (e.g., up–high) being processed faster than incongruent ones (e.g., down–high). This shows that masked priming with spatial words can take place even when non-semantic stimulus-response mapping is prevented (prime words never appeared as targets), provided that prime duration is slightly increased as compared to previous experiments (50ms, in this specific case). Importantly, despite primes being shown for slightly longer than in experiments 1 and 2, they were reliably kept outside participants' awareness.

Much previous work has shown that longer presentation times for the primes generally yield more solid semantic priming effects (e.g., Holcomb, Reder, Misra, & Grainger, 2005), and our results sit well with this literature. Some of this research also focused on the time elapsed between the presentation of the prime and the appearance of the target word, the so–called Stimulus Onset Asynchrony (SOA; e.g., Holcomb & Grainger, 2009), which can be varied independently from the duration of the prime (varying the display time of the backward mask). In this case, results are less consistent, with longer SOA yielding weaker priming effects at least in some cases (Holcomb & Grainger, 2007). Our data cannot distinguish which of these factors is really driving the effect, since SOA and prime duration covary in this experiment. Note, however, that this does not affect at all the core issue of this work—we were only interested in SOA/prime presentation time insofar as they allowed semantic priming to emerge, so that we can study whether this effect is embodied or symbolic in nature.

Coming back to the central issue of the paper, Experiment 3 demonstrates that spatial words yield masked priming that is genuinely semantic in nature. We still do not know, however, whether this is due to a symbolic relationship in semantic memory between prime and target words; or to the fact that task–relevant information is mistakenly taken up from the primes to guide the task-dictated decision; or, again, to an embodied mechanism whereby seeing, e.g., *up*, although briefly and outside awareness, pre–activates upward movements.

There is one feature of the spreading activation account that differentiates it from the other two: primes and targets need to have related meanings, as priming is impossible otherwise. This is the rationale of Experiment 4, where we made use of target words (e.g. car, boat) that are totally unrelated to the spatial primes, yet maintain a spatially oriented response (upward/downward movement). If a priming effect emerges (e.g. upward primes facilitates upward movements), it cannot be due to the symbolic relationship between prime and target. This would rule out the Spreading Activation account and implicate the Evidence Accumulation account and/or the Embodied Priming account in the semantic priming effect we are observing in these experiments.

Experiment 4

Methods

Participants. Twenty-six participants were recruited in this experiment, none of which had participated in the previous ones. Fifteen were females, and their mean age was 25. They all reported no neurological and/or reading problems, normal or corrected–to–normal vision, and were native Italian speakers. Participants were paid 8 Euros or given course credits in exchange for their time.

Stimuli. The primes were the same Italian spatial words used in previous experiments. They were divided into two groups of four, each including two downward and two upward words, which were rotated across participants in a Latin square design, i.e., half of the participants saw one group of prime words, half saw the other. We adopted this design in order to make sure that, overall, exactly the same prime words that were used in Experiment 3 were also used here. Also, this design guarantees that each participant is shown four different prime words during the experiment, which, again, is identical to what happened in Experiment 3. Targets were four words that refer to either water or ground transportation means, i.e., auto (car), treno (train), nave (ship), and barca (boat).

Apparatus and procedure. In the target–response task, participants were required to judge whether the target word represented a water or a ground transportation mean, and press a colored response button accordingly (red for water transportation and green for ground transportation, or vice versa). As in previous experiments, buttons were arranged vertically, so that participants had to respond with either an upward or a downward movement. Congruent trials were trials in which the spatial prime (e.g. "above") corresponded to the required response movement (e.g. upward movement). Color position was rotated across participants, so that half of them had the red button below the starting hand position, and half had it above the starting hand position.

Given the structure of prime-target pairs in this experiment, the prime-visibility task in which the participants had to judge if the prime-target pairs were semantically congruent or incongruent was eliminated. Because no difference between the three prime visibility tasks emerged in previous experiments, this should not be matter of concern. Every other aspect of the experiment, including the trial timeline, the overall trial number, and the response box, was identical to the previous experiments.

Results

Target-response task. One participant could not perform the target-response task and one always responded *no* in the prime visibility task. Data from these subjects were not considered in the analysis. The average accuracy rate was ~99%. Data were pre–processed as in previous experiments, which resulted in the exclusion of ~9% of trials. The overall mean response time was 732 ms.

Response times were analyzed through a mixed ANOVA with Congruity (prime congruent with movement vs. prime incongruent with movement) and Response Code (ground transportation assigned to the upper key vs. ground transportation assigned to the lower key) as predictors. The Response Code factor was included in the analysis only as a way to check that the position assigned to each category did not affect the data. There was a main effect of Congruity, $F(1,23)= 8.75$, $p= .007$, $\eta^2= 0.28$ (Figure 3). Participants were faster in the congruent condition (RTs= 729ms) than in the incongruent condition (RTs= 735ms). There was no effect of Response Code, $F(1,23)= 0.08$, $p= .78$, $\eta^2= 0.004$, and no Congruity by Response Code interaction, $F(1,23)= 0.01$, $p= .93$, $\eta^2=<0.01$, showing that the priming effect was unaffected by the particular association between transportation mean and vertical part of space. No effect emerged in the error rate analyses.

Prime visibility task. None of the participants reported having noticed the primes. As in the previous experiment, average d-prime was low (0.42, SD= 0.88), although significantly different from zero ($t(23)= 2.35$, $p= .03$). Average d-prime values were comparable across prime visibility tests (Semantic judgment= 0.49; Letter judgment = 0.35; $t(22)= 0.36$, $p= 0.71$). Again similar to Experiment 3, the Greenwald regression method shows that the intercept of the d prime–priming effect regression line was significantly above the origin, suggesting a truly subliminal effect (see Figure 3). Priming effect and d-prime values were not correlated ($r= -0.22$; $t(22)= -1.08$, $p= 0.29$).

-- Figure 3 about here --

Discussion

In this experiment targets were not semantically related with the spatial primes, which ruled out the possibility of masked priming based on simple spreading activation. Nevertheless reliable facilitation emerged.

Two mechanisms are left to explain the results of Experiment 4. Spatial primes could have directly influenced response movements as predicted by the embodied account—seeing "up" would make people faster in making upward movements. It is interesting to note that, although these data can be interpreted as consistent with embodied semantics, they are at odds with those reported by Dudschig et al. (2014), who used a similar paradigm: We found a facilitation effect, whereas these authors reported negative priming, that is, incongruent prime-response pairs led to faster RTs compared to congruent ones. Although Experiment 4 is different in many regards from Dudschig et al. experiment (e.g., different primes, different targets, longer prime duration, unimanual responses), the reasons of these opposite results are not clear. We will come back to this issue in the General Discussion.

Evidence Accumulation and Source Confusion can also account for the results of Experiment 4. We instructed subjects to associate land and water transportations with red and green buttons located either up or down relative to the starting hand position. In such a context, the task–dictated decision that participants had to make was moving up vs. moving down, a decision that can be influenced by the evidence provided by the spatial primes. So, if primes were used to gather evidence for the task decision due to source confusion, we would indeed expect congruent primes to yield faster response times than incongruent ones.

One way to tease apart the two competitors left standing after four experiments was to prevent any spatial mapping of our instructions. If the task–dictated decision is not spatial in nature, there is no way in which spatial primes can inform it. Thus, erroneously gathering evidence from the prime should not affect the decision, nor response times. On the contrary, embodied priming would still be possible: Regardless of the decision to be made, as long as the response implies an upward or downward movement, primes like ‘up’ and ‘down’ should yield facilitation. So, in Experiment 5 we impeded any spatial connotation of the response codes by varying the position of the colored buttons on a trial by trial basis, i.e., the red button would be the upper button on some trials and the lower button on some others. In spatial terms, this means varying the target–key mapping trial by trial, which clearly makes it impractical to map responses onto fixed spatial positions.

In order to maximize the chance of seeing embodied priming, we made target classification simpler. This was done because changing the position of the colored button trial by trial would clearly make the task more difficult, and thus response times longer; and we know that masked semantic priming tends to emerge more clearly (exclusively, in some cases) with quick responses (e.g., Greenwald et al., 1996; Kiefer & Spitzer, 2000). So, in the next experiment participants would decide which button to press based on a simple word–color matching task (Dudshig et al., 2014).

In the Experiment 5 participants saw color words (yellow and purple)[1] as targets, appearing on the screen with a yellow and a purple rectangle below and above (see Fig 4). They had to press the key (upper, lower) corresponding to the rectangle that matched the color word. Importantly, the position of the colored rectangles varied trial by trial, i.e., sometimes the yellow was up and the purple down, and sometimes the reverse.

In this paradigm, targets could no longer be associated with a fixed spatial code (e.g. target word – upward movement), but were instead associated with a fixed color code (target word – colored rectangle). Thus participants are likely to accumulate evidence to solve the

[1] We changed the colors from green and red to yellow and purple. The reason for this is that the former pair is quite meaningful (red and green consistently signals stop and go, respectively), and we did not want this further semantic association to interfere with the semantic processing potentially relevant for priming. Also, red and green are the colors of traffic lights, which are arranged along the vertical space in a very consistent fashion.

task on the basis of the color association. In other words, the decision dictated by the task is likely to be "is the word associated with the yellow/purple rectangle?" a decision that is not facilitated by the evidence provided by spatial primes (above, below). We believe that this procedure minimizes the chance of semantic priming based on Evidence Accumulation and Source Confusion. Nevertheless, participants were still required to perform either upward or downward movements, which may have been facilitated (Ansorge et al., 2010) or inhibited (Dudschig et al., 2014) by congruent spatial words.

Experiment 5

Methods

Participants. Thirty-two participants were recruited in this experiment from the same population as in previous experiments. Twenty-seven of these participants were females, and their mean age was 22. Participants were paid with 8 Euros or given course credits in exchange for their time.

Stimuli. The primes were the same Italian spatial words used previously, again divided into two groups of four that were rotated across participants in Latin Square design. Target words were the two color-names giallo (yellow), and viola (purple).

Apparatus and procedure. Participants were involved in a word–color matching task. They were informed that during the experiment they would see a fixation point, followed by a string of uppercase letters to signal the arrival of the target, followed in turn by the target screen, made up of a color word (either *purple* or *yellow*, in white font), and two colored rectangles immediately below and above it (see Figure 4). Their task was to press the button on the response box corresponding to the color indicated by the word.

Because previous experiments had consistently shown that d–prime was comparable across different prime–visibility tasks, we only used one in Experiment 5, i.e., the lexical decision task where participants judged whether the prime was a real word vs. a string of identical uppercase letters. We chose this task because it can be performed on the basis of perceptual differences alone, without the need for recognizing the prime word either lexically or semantically. So, we gave prime visibility the best possible chance to emerge in the d–prime values.

Experiment 5 is identical to previous experiments in all other aspects, with the only exception that a few more practice trials were offered to the participants (n=58) in consideration of the increased difficulty of the task.

-- Figure 4 about here --

Results

Target-response task.

Data were pre–processed as in previous experiments, leading to the exclusion of ~10% of trials. The average accuracy rate was ~99% and the overall mean response time was 757ms. This last figure reveals that response times were slower in this experiment than in previous ones, which may jeopardize the chance of seeing a semantic priming effect (Ansorge et al., 2010; Greenwald et al., 1996; Kiefer & Spitzer, 2000). In order to address this issue, we will consider response time as a further predictor in our models, so that priming can be gauged separately for the fastest 50% and the slowest 50% of RTs (speed was modeled as a dichotomous variable based on a subject-wise median split).

A 2–by–2 ANOVA was run on log–transformed RTs with the factors Congruity (prime congruent with response movement vs. prime incongruent with response movement) and Response Speed (fastest 50% bin vs. slowest 50% bin) as predictors. There was no main effect of Congruity, $F(1,31)= 0.68$, $p= 0.41$, $\eta^2= .021$, a (trivial) main effect of Response Speed, $F(1,31)= 907.93$, $p<0.001$, $\eta^2= .97$, and no Congruity by Response Speed interaction, $F(1,31)= 1.09$, $p= .30$, $\eta^2= .03$. Average response times in the congruent and incongruent conditions were 758 ms and 756 ms respectively (Figure 5). No effect emerged in the error rate analyses.

Prime visibility task.

As in Experiment 3 and 4, the average d-prime value was low (0.22, SD= 0.34), although significantly different from zero ($t(31)= 3.72$, $p< .001$). The Greenwald regression method (Greenwald, Klinger, & Schuh, 1995) showed that priming was not significantly above or below zero when d–prime was zero (Figure 5). Priming effect and d-prime values were not correlated ($r= 0.04$; $t(30)= 0.24$, $p= 0.81$).

-- Figure 5 about here --

Discussion

In this experiment, we designed the task in order to exclude the possibility that targets were transiently associated with a spatial code during the experiment. We achieved that by varying the spatial response (upward movement, downward movement) associated with each target category on a trial–by–trial basis. This arrangement prevents the emergence of a symbolic priming effect based on Evidence Accumulation. Conversely, it maintains the possibility that response movements could be directly modulated by the long-term meaning of the spatial primes, i.e., embodied, masked semantic priming. Nevertheless, no significant priming effect was observed.

Before taking these data to show that no embodied semantic representations are activated outside awareness, however, we need to demonstrate that the null effect observed here is not simply due to the complexity of the task, and that symbolic semantic priming can emerge in the same conditions. So, in Experiment 6 we kept the structure of Experiment 5, but ruled out the possibility of embodied priming by using non-spatial primes. Target words were again two color words, *yellow* and *green*, as in Experiment 5. Again identical to the previous experiment, these words appeared on the screen together with two symbols located above and below them, which indicated the target–key mapping on a trial–by–trial basis. The symbols represented males and females, as shown in Figure 6, and participants were asked to press the key corresponding to the position of the male symbol when they saw the word *yellow*, and the key corresponding to the position of the female symbol when they saw the word *green* (or vice-versa, counterbalanced across subjects). Primes were non–spatial words (*man*, *woman*, *male*, and *female*) that could be either congruent or incongruent with the trial relevant symbol, e.g., prime word is *man* when participants have to press the button corresponding to the male symbol vs. prime word is *man* when participants have to press the button corresponding to the female symbol.

This paradigm leaves no room for embodied priming. Symbolic priming is instead possible according to Evidence Accumulation and Source Confusion. The task–relevant hypothesis to gather evidence for is whether going for the male button vs. female button. Gender–connoted primes can clearly provide information to address this hypothesis. (Note that primes and targets are completely unrelated as in Experiment 4, which allows us to rule out the possibility that priming comes from simple spreading activation).

Experiment 6

Methods

Participants. Thirty–two participants from the same population as in previous experiments were recruited for this study. Twenty-nine of them were females, and their mean age was 23 years. Participants were paid with 8 Euros or given course credits in exchange for their time.

Stimuli. Four different words connoting gender were used as primes, namely donna (woman), femmina (female), uomo (man), and maschio (male). Targets were the two color words verde (green), and giallo (yellow). We replaced purple with green because, at least in the Italian culture, the former is somewhat connoted for gender, e.g., (light) purple clothes for children are typically girl clothes. Target words were presented together with two figures representing men and women (see Figure 6).

Apparatus and procedure. In the target response task participants were required to press the button on the response box corresponding to the, e.g., male figure if the target word was *yellow*, or female figure if the target word was *green*. Color–gender association was counterbalanced across participants so that half of them paired yellow with male and green with female, and half paired yellow with female and green with male. In order to avoid any remapping of the task instructions in spatial terms, the figure position varied randomly across trials.

In all other ways, including the trial timeline, the response box, the prime visibility task, and the number of trials, Experiment 6 was identical to Experiment 5.

-- Figure 6 about here --

Results

Target-response task. Data were preprocessed as in previous experiments, which led to the exclusion of ~10% of trials. The average accuracy rate was ~98% and the overall mean response time was 856ms. Because this latter figure reflected the slowest average RT across all the experiments, we kept response speed as a covariate in our analyses, as in the previous experiment.

A 2–by–2 ANOVA was run over log–transformed response times with the factors Congruity (primes congruent with the response gender vs. primes incongruent with the response gender) and Response Speed (quickest 50% of the RTs vs. slowest 50% of the RTs) as predictors. This analysis revealed a main effect of Congruity, $F(1,31)= 4.22$, $p= .048$, $\eta^2= .12$, a (trivial) main effect of Response Speed, $F(1,31)= 511.21$, $p<.001$, $\eta^2= .94$, and a significant Congruity by Response Speed interaction, $F(1,31)= 9.70$, $p= .004$, $\eta^2= .24$.

Pairwise comparisons showed that the congruity effect was highly significant for faster RTs (5 ms; $F(1,31)= 18.61$, $p< .001$, $\eta^2= 0.37$), but absent for slower RTs (-1 ms; $F(1,31)= 0.41$, $p= .53$, $\eta^2 = 0.01$). No effect emerged in the error rate analyses.

These results show a different pattern than the pattern observed in Experiment 5 and 6. We tested the reliability of this difference by carrying out a cross–experiment analysis. Indeed, this revealed a significant Congruity by Experiment interaction, $F(1, 62)= 3.89$, $p= 0.05$, $\eta^2= 0.06$, and, more critically, a significant Congruity by Response Speed by Experiment interaction, $F(1, 62)= 7.74$, $p= 0.007$, $\eta^2 = 0.11$.

Prime visibility task.

As in Experiments 3–5, the average d-prime value was low (0.40, SD=0.49), but significantly different from zero ($t(31)= 4.56$, $p< .001$). The Greenwald regression method (Greenwald, et al., 1995) revealed that the intercept of the regression was significantly above the origin for data points in the first quantile, indicating a subliminal effect of semantic priming with quick RTs (Figure 7a). This effect disappeared when longer latencies (in the second quantile) were considered—as shown in Figure 7b, the 95% CI for the priming effect includes zero when d–prime is zero. Priming effects did not correlate with d-prime values (all r between -0.20 and 0.17, all t between -1.10 and 0.89, all $p > 0.27$).

-- Figure 7 about here --

Discussion

In Experiment 6, we used the same experimental paradigm as in Experiment 5. However, we changed the nature of the prime words (gender words, rather than spatial words) and the probes determining the target–button mapping (gender symbols, rather than colors) so as to prevent embodied priming, and allow symbolic semantic priming based on Evidence Accumulation. The priming effect was highly significant, at least for shorter response times (Greenwald, 1996; Kiefer & Spitzer, 2000), contrary to what we have found in Experiment 5, where embodied priming was allowed and Evidence Accumulation priming was prevented.

-- Table 1 about here --

GENERAL DISCUSSION

In six experiments we investigated the nature of masked semantic priming using words referring to the vertical spatial axis (e.g., up, down). Previous studies showing such an effect have claimed that its nature is embodied, i.e., primes yield facilitation by activating their corresponding sensorimotor information (e.g., Ansorge et al., 2010; Boulanger et al., 2006; Dudschig et al., 2014). However, we argued in the Introduction that such a claim suffers from at least two fundamental problems: (i) Priming is also open to non–embodied, fully symbolic interpretations; and (ii) the nature of the putative embodied effect was found to be facilitatory in some cases, and inhibitory in others.

The results of the six experiments uncover the following five facts (see also Table 1):

(i) At a very short prime duration[2] (33ms, in this case) reliable semantic priming emerged when a Stimulus-Response Mapping mechanism could take place (e.g. when prime words were also used as targets; E1). Yet, spatial words do not yield any priming when Stimulus-Response Mapping was prevented by using different sets of words as primes and targets (E2), although priming could have emerged thanks to symbolic or embodied mechanisms (Ansorge te al., 2010; Dudschig et al., 2014).

(ii) With a slightly longer prime duration, during which primes remain subliminal, a reliable semantic priming effect emerged even when any Stimulus-Response mapping was prevented (E3).

(iii) It is not necessary for primes and targets to be semantically related in order to see an effect (E4), contrary to the prediction of Spreading Activation mechanisms, but according to Evidence Accumulation and Source Confusion and Embodied Priming (EP).

(iv) When Embodied Priming is the only mechanism by which an effect could arise, there is no priming effect (neither facilitatory nor inhibitory; E5).

(v) When Evidence Accumulation and Source Confusion is the only mechanism by which an effect could arise, priming does emerge, and it is facilitatory (E6).

These results challenge radical theories of Embodied Semantics by showing that there is no evidence that unconsciously perceived words activate motor programs solely on the basis of their long-term meaning. Critically, this lack of embodied priming is not simply due to the fact the masked primes do not reach out to any semantic analysis. If it were so, we

[2] As acknowledged in the Discussion of Experiment 3, prime presentation time coincides with Stimulus Onset Asynchrony (SOA) throughout this paper, so we do not know which factor is most important in determining the emergence of the priming effect. This, however, is quite irrelevant from the perspective of the main goal of this paper, which is not assessing the role of prime presentation time or SOA, but clarifying whether semantic priming is embodied or symbolic in nature.

would have failed to observe masked semantic priming overall. Thus, motor activation is not an automatic and necessary part of semantic processing, i.e., there is at least one condition (lack of awareness) where we see semantic processing, but no sensorimotor activation.

This conclusion is in line with several behavioral and neuroimaging studies showing that embodiment effects fade away under conditions in which task requirements make less salient the sensorimotor aspects of stimuli or response codes (Estes, Verges & Barsalou, 2008; Hoedemaker & Gordon, 2014; Kan, Barsalou, Olseth Solomon, Minor, & Thompson-Schill, 2003; Lebois, Wilson, Mendenhall, & Barsalou, 2014; Niedenthal, Winkielman, Mondillon, & Vermeulen, 2009; Papeo, Rumiati, Cecchetto, & Tomasino, 2012; Raposo, Moss, Stamatakis, & Tyler, 2009; Rüschemeyer, Brass & Friederici, 2007; Santiago, Ouellet, Roman, & Valenzuela, 2012; Thornton, Loetscher, Yates & Nicholls, 2013; Dam, Brazil, Bekkering, & Rueschemeyer, 2014). For instance, in one experiment participants judged emotional and neutral words while facial electromyographic activity was recorded from the cheek, brow, eye, and nose regions (Niedenthal et al., 2009). Results showed emotion-specific electromyographic activity in an emotion-focused (i.e., semantic judgment), but not in a perception-focused (i.e., font judgment) processing task on the same words. Estes et al. (2008) asked their participants to engage in a stimulus detection task in which target stimuli appeared either at the top or the bottom of a computer screen. The appearance of the target was preceded by a word prime in the central fixation denoting objects with typical upper or lower location (e.g. hat - boots). They found an effect of interference: Up-related primes interfered with the localization of upper targets and down-related primes interfered with the localization of lower targets. Crucially, the interference effect faded away when primes were masked. Thornton and colleagues (Thornton et al., 2013) also tested whether words associated with spatial locations automatically biases behavior toward these locations in space. Participants had to classify words (natural vs man-made objects) presented in the center of a computer screen by pressing two keys arranged vertically. As in previous experiments upward-related words facilitated upward movements and downward-related words facilitated downward movements. Yet, the effect disappeared in a target-detection task (similar to Estes et al., 2008) that used the same spatial words as probes, but required only one response key. The authors concluded that perceptual biases induced by spatial words is due to conflicts during response-selection processes (i.e., the task-dictated decision) more than automatic shift of spatial attention or motor activations.

Likewise, several neuroimaging studies have shown that sensorimotor activations during language understanding are context- and task-dependent. For instance reading an action verb such as “grasp” does not activate motor or premotor cortices if the verb appears in a metaphorical expression (e.g. “to grasp the idea”; Raposo et al., 2009; but see Boulanger et al., 2009) or as a part of a morphologically more complex German abstract verbs (a comparable example in English would be the word *prehending* in *comprehending*). Consistently, Kan and colleagues (Kan et al., 2003) showed that, in a property-verification task (e.g. “do cats have whiskers?”), the visual association cortex was active only when the task was made more difficult and prompted to the use of mental imagery.

These and other similar results underlie the contextual variability of so-called “embodied” effects and, together with the results of this paper, contrast with the hypothesis that sensorimotor processes are automatically activated from the early stages of word recognition and constitute an intrinsic part of semantic processing.

Comparison with previous masked priming studies

The hypothesis of highly automatic (Boulanger et al., 2006; Pülvermuller, Hauk, Nikulin, & Ilmoniemi, 2005) and maybe necessary (Ansorge et al., 2010) sensorimotor processing during language understanding has been challenged repeatedly by several studies showing the context- and task-dependency of this motor and sensory activity and its effects. However, previous experiments testing ES using unconscious priming paradigms seem to go against this tendency. In this paper we reconcile these findings with the extant literature by showing that previous instances of Embodied Semantic Priming can be explained also by disembodied mechanisms.

Yet, the results of one study (Dudschig et al. (2014), appear more problematic in this regard. In this experiment, masked priming could not be explained on the basis of simple stimulus-response mapping, given that primes never appeared as targets. Nevertheless, an Evidence Accumulation (fully symbolic) priming mechanism could have accounted for their results, since targets could be associated with spatial coordinates due to the fixed response code, as in our experiment 4. Although one would predict a positive priming effect as a consequence of this mechanism (as we observed in our experiments 4 and 6), Dudschig et al. observed a negative semantic priming effect. Dudschig et al. (2014) proposed that whereas embodied semantic priming can easily explain a negative priming effect, symbolic priming mechanisms cannot. Yet, this claim is not necessarily true. Negative masked semantic priming has been already observed in the literature, although its origin is not clear (Bermeitinger, Frings, & Wentura, 2008; Carr & Dagenbach, 1990; Dagenbach, Carr & Wilhelmsen, 1989; Wentura & Frings, 2005). For instance, Wentura & Frings (2005) reported negative semantic priming for masked words when primes were category names (e.g., *INSECTS*, *FLOWERS*) and targets category exemplars (e.g., *fly*, *rose*). Congruent pairs led to longer RTs than incongruent ones, and this effect was stronger for less prototypical, exemplars (bed-bug and dahlia) than highly prototypical ones (fly and rose). Likewise, in a masked priming experiment with pictures, highly prototypical targets showed positive semantic priming, whereas low prototypical targets showed a negative one (Frings, Göbel, Mast, Sutter, Bermeitinger, & Wentura 2011). That is, semantically related prime-target pairs with low prototypicality were processed slower compared to unrelated pairs. Although the actual mechanisms of negative priming remain debated (but see Frings et al. 2011; Wentura & Frings, 2005; for an explanation base on Center-Surround Inhibition) this paradoxical effect may explain the results of Dudschig et al. In fact, they used primes that, although usually associated with higher or lower positions in space (e.g., castle, mouse), are not necessarily highly prototypical members of the semantic categories “UP” and “DOWN”. Conversely, in our Experiment 4, primes were words that unambiguously referred to vertical spatial positions (e.g. up, down, above, below), and probably connoted very little additional semantic features. The difference in prototypicality between the primes used in the two experiments may be the reason for the opposite sign of the priming effects observed. In Dudschig et al. (2014) the low prototypicality of the primes may have encouraged (disembodied) CSI mechanisms to take place (Frings et al. 2011; Wentura & Frings, 2005).

Not only can the negative priming effect observed by Dudschig et al. be explained (at least in principle) by symbolic mechanisms, but the embodied account provided by the authors presents several problems. According to them, reverse priming is compatible with previous experiments showing that symbols like arrows (e.g., >>) presented subliminally inhibit a right/left response to compatible target arrows (>>), and facilitate incompatible responses (<<; Eimer & Schlaghecken, 1998). This effect is ascribed to a central mechanism that inhibits perceptual-motor links in order to prevent behavior from being affected by irrelevant information (Eimer, 1999). Dudschig and colleagues suggested that the same mechanism could explain their results with subliminal word primes: Spatial words automatically activate congruent motor programs that are immediately inhibited by a central control mechanism. Yet, it should be taken into account that the classic result by Eimer and colleagues (Eimer, 1999; Eimer & Schlaghecken, 1998) is obtained in cases in which the same stimuli (e.g., << and >>) are seen both as targets and primes, with the effect being completely explained at the level of short-term stimulus-response mapping during the experiment, independent of semantics (Eimer & Schlaghecken , 1998, Exp. 2 and 3; see also Damian, 2001, for a similar account). The fact that the effect is obviously non-semantic becomes clear in Eimer & Schlaghecken (1998) Experiment 2. When arrows are used as primes, but letters are used as target (LL for left, RR for right), no effect (neither facilitation nor inhibition) is found. Thus, given the non-semantic nature of previously reported inhibitory effects, comparisons to similar effects based on semantic processing should be made cautiously, especially on the basis of Boulanger et al. results (Boulanger et al. 2008; discussed in the Introduction), which show that negative masked priming can be obtained with meaningless consonant strings. Additionally, an embodied account should predict similar negative priming for Ansorge et al.'s experiments and our Experiment 1. In these cases the comparison to Eimer & Schlaghecken (1998) is more licensed since the same stimuli were used as primes and targets. However, we and Ansorge both observed a positive priming effect. The reason of this discrepancy remains elusive. Future studies are needed to determine whether negative semantic priming like that observed by Dudschig and colleagues is a signature of embodied mechanisms or can be entirely explained in symbolic terms.

Conscious vs. unconscious semantic processing

Our results suggest that conscious access to word meaning may be necessary to observe sensorimotor activations in the context of semantic processing. This does not necessarily mean that the involvement of the sensorimotor system observed when words are overtly presented is merely a byproduct of the "real" semantic analysis. To date, several studies suggest that the sensorimotor system plays an active role in language understanding, although it may not be necessary for it (see Willems & Casasanto, 2011, Meteyard et al., 2014, for approaches that emphasize the functional, but flexible role of the sensorimotor system in language understanding).

However, our results stand in contrast to what has been called the "elaborate processing hypothesis" (Kunde, Kiesel, & Hoffmann, 2003), according to which conscious and unconscious words undergo the same levels of semantic processing. The data presented here suggest otherwise, at least to the extent that unconscious semantic analysis may not involve sensory and motor areas that are only active when words are processed consciously.

Embodied effects associated with language comprehension may be the product of a process of integration by which linguistic information (lexical, semantic, syntactic) is integrated with non-linguistic information stored in modality-specific or association cortices. Although some form of integration can take place outside of awareness (Mudrik, Faivre & Koch, 2014; Faivre, Mudrik, Schwartz, & Koch, 2014), several theories suggest that consciousness plays a crucial role in combining information coming from different modalities and/or cognitive domains (Baars, 2002; Dehaene & Naccache, 2001; Tononi, 2008; Varela, Lachaux, Rodriguez, & Martinerie, 2001), especially when the information to be integrated is new or relatively complex (see Mudrik et al., 2014, for a review). As a consequence, outside of awareness, information processing may be confined to highly specialized and segregated neural networks (Kouider & Dehaene 2007). The on-line activation of distant non-linguistic brain areas such as prefrontal, sensorimotor and association cortices, may be the trademark of an integrated construction of word meaning which requires conscious access.

Importantly, some semantic categories (e.g. emotion words) may be more easily integrated with sensorimotor processes than others (Naccacche et al., 2005). For instance, there is evidence that emotional words can activate the amygdala even when presented subliminally (Nacacche et al., 2005). That is, categories that have a strong indexical relationship with their referents (e.g., they more often co-occur with specific actions or sensations) may behave differently than spatial words, and may integrate extra-linguistic information even when unconsciously processed.

Additionally, future work should test whether, unlike words, pictorial stimuli elicit more automatic and unconscious sensorimotor activity. Indeed pictures are iconic, and may consistently activate sensorimotor aspects of their referents. Such a comparison may also have direct behavioral application, for instance, to decide whether words or images should be used to signal dangerous situations that require immediate actions. Further studies are warranted to understand the possibilities and limitations of unconscious semantics and to shed light on the role of consciousness in the understanding language.

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Table 1. Experiments sum-up table

Experiment	S-R mapping	Spreading Activation	EASC	Embodied priming	Prime Duration	Priming effect
Exp 1	YES	YES	YES	YES	33 ms	19ms ***
Exp 2	NO	YES	YES	YES	33 ms	2ms
Exp 3	NO	YES	YES	YES	50 ms	16ms ***
Exp 4	NO	NO	YES	YES	50 ms	6ms ***
Exp 5 (Overall)	NO	NO	NO	YES	50 ms	-2ms
fast RTs	NO	NO	NO	YES	50 ms	-2ms
slow RTs	NO	NO	NO	YES	50 ms	0ms
Exp 6 (Overall)	NO	NO	YES	NO	50 ms	3ms *
fast RTs	NO	NO	YES	NO	50 ms	5ms ***
slow RTs	NO	NO	YES	NO	50 ms	-1ms

Note. S-R mapping = Stimulus-Response mapping; EASC = Evidence Accumulation & Source Confusion.
Significance levels : *p<.05. **p<.01. ***p<.001.

Figures

Figure 1

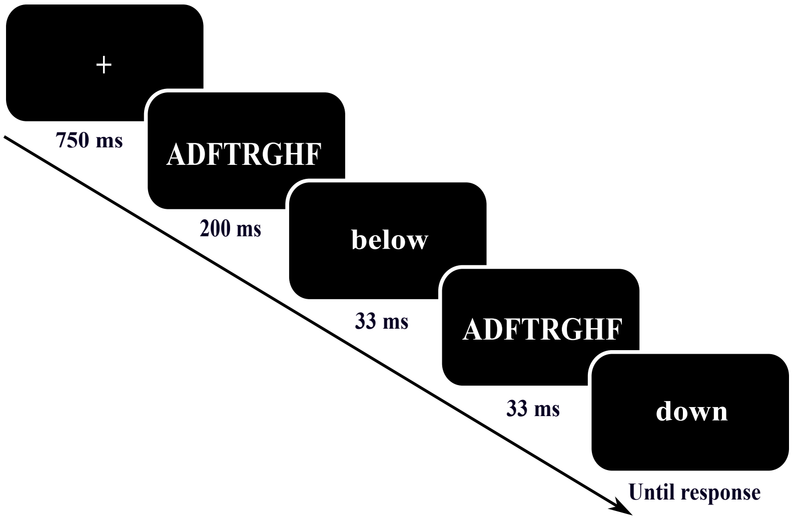

Figure 2

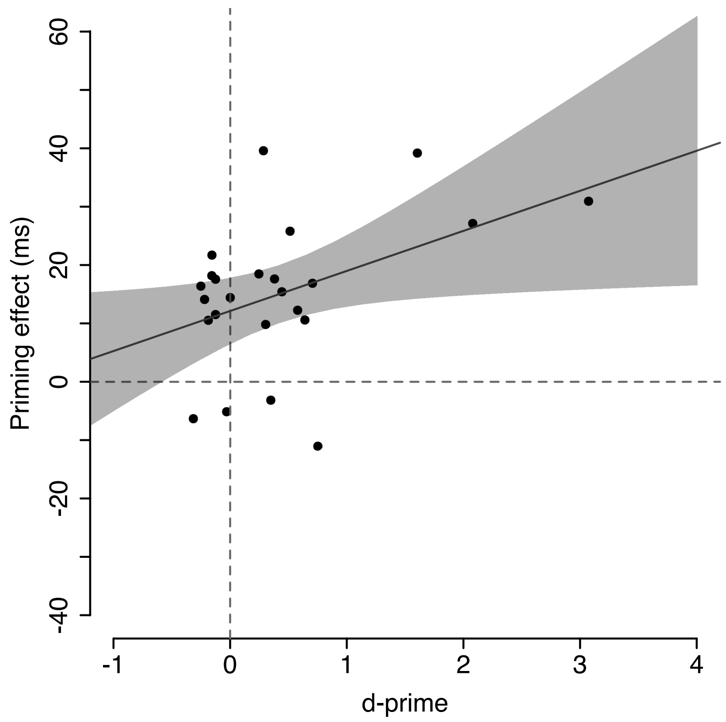

Figure 3

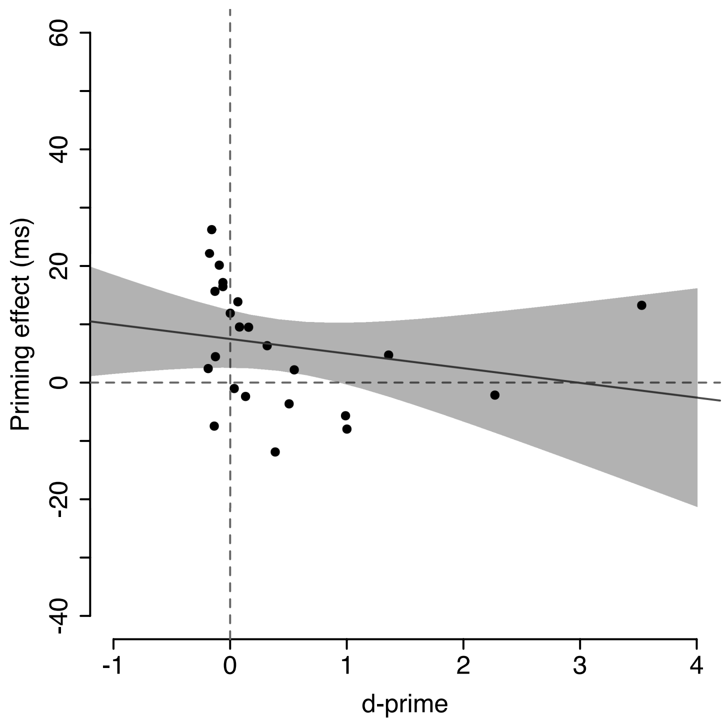

Figure 4

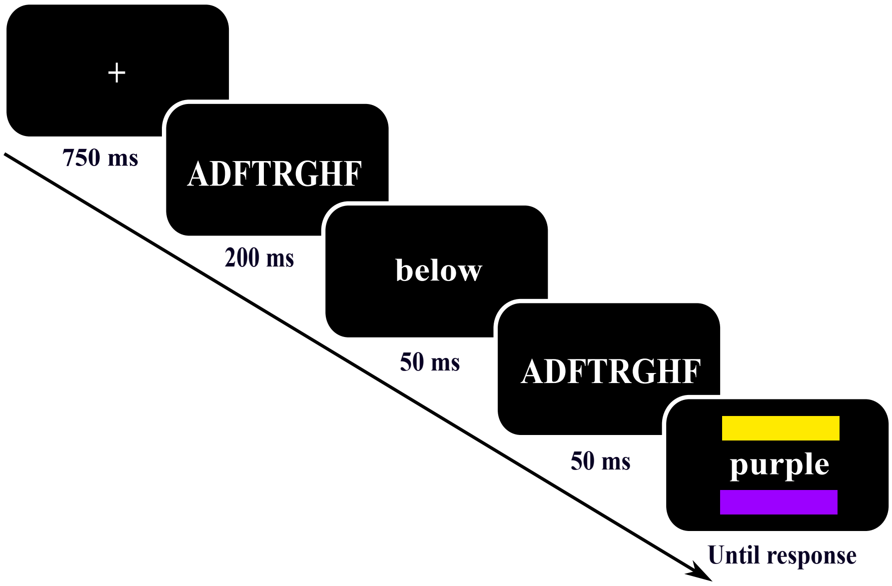
+
750 ms
ADFTRGHF
200 ms
below
50 ms
ADFTRGHF
50 ms
purple
Until response

Figure 5

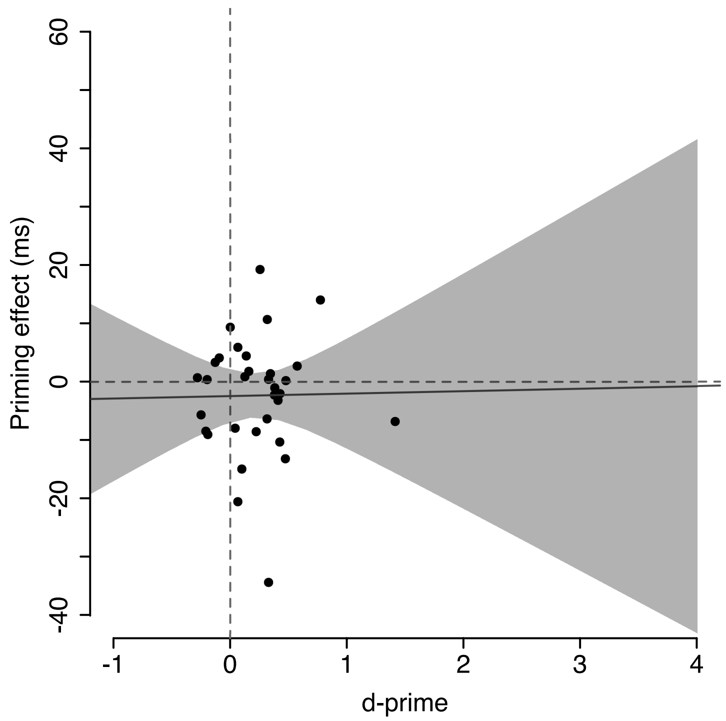

Figure 6

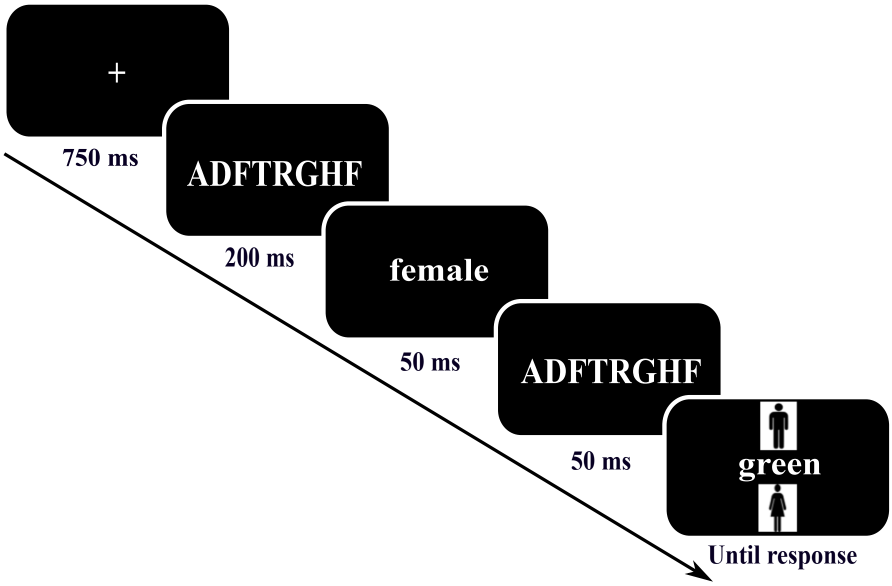
+
750 ms
ADFTRGHF
200 ms
female
50 ms
ADFTRGHF
50 ms
green
Until response

Figure 7

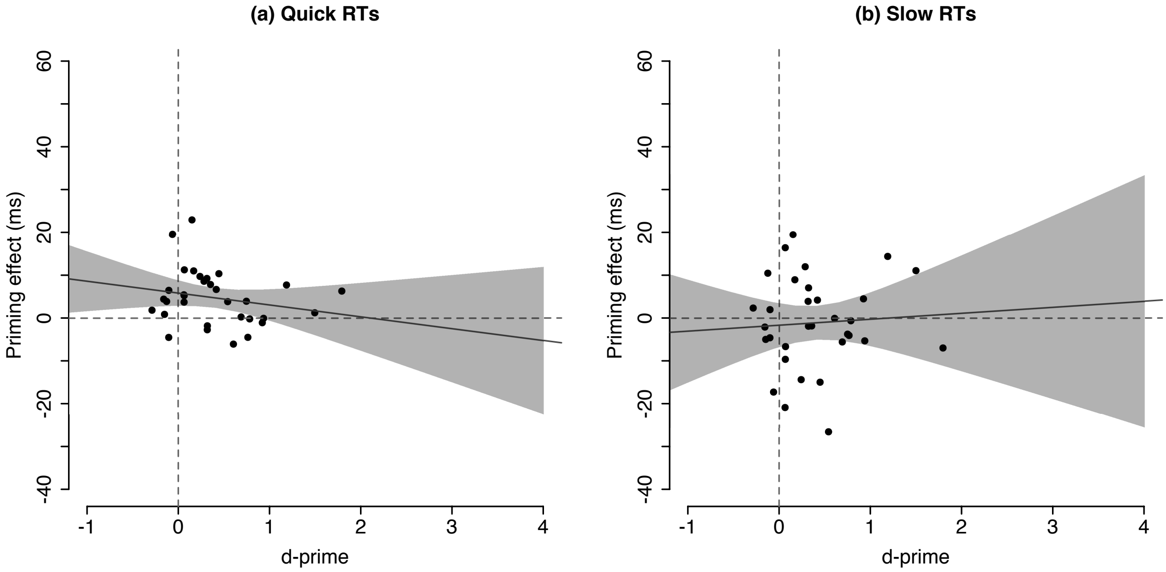
(a) Quick RTs
Priming effect (ms)
60
40
20
0
-20
-40
-1
0
1
2
3
4
d-prime
(b) Slow RTs
Priming effect (ms)
60
40
20
0
-20
-40
-1
0
1
2
3
4
d-prime

Figure captions

Figure 1. Trial timeline in Experiment 1.

Figure 2. . Regression of priming effect against prime visibility (as assessed though d–prime in the prime visibility task) in Experiment 3. Points represent participants, and the shaded area indicates the 95% confidence interval of the regression line. Note that priming is measured by subtracting mean RTs on congruent trials from mean RTs on incongruent trials, that is, positive values indicate facilitation.

Figure 3. Regression of priming effect against prime visibility (as assessed though d–prime in the prime visibility task) in Experiment 4. Points represent participants, and the shaded area indicates the 95% confidence interval of the regression line. Note that priming is measured by subtracting mean RTs on congruent trials from mean RTs on incongruent trials, that is, positive values indicate facilitation.

Figure 4. Trial timeline in Experiment 5.

Figure 5. Regression of the priming effect against prime visibility (as assessed though d–prime in the prime visibility task) in Experiment 5. Points represent participants, and the shaded area indicates the 95% confidence interval of the regression line. Note that priming is measured by subtracting mean RTs on congruent trials from mean RTs on incongruent trials, that is, positive values indicate facilitation.

Figure 6. Trial timeline in Experiment 6.

Figure 7. Regression of priming effect against prime visibility (as assessed though d–prime in the prime visibility task) in Experiment 6, computed separately for quick RTs (panel a) and slow RTs (panel b). Points represent participants, and the shaded area indicates the 95% confidence interval of the regression line. Note that priming is measured by subtracting mean RTs on congruent trials from mean RTs on incongruent trials, that is, positive values indicate facilitation.